



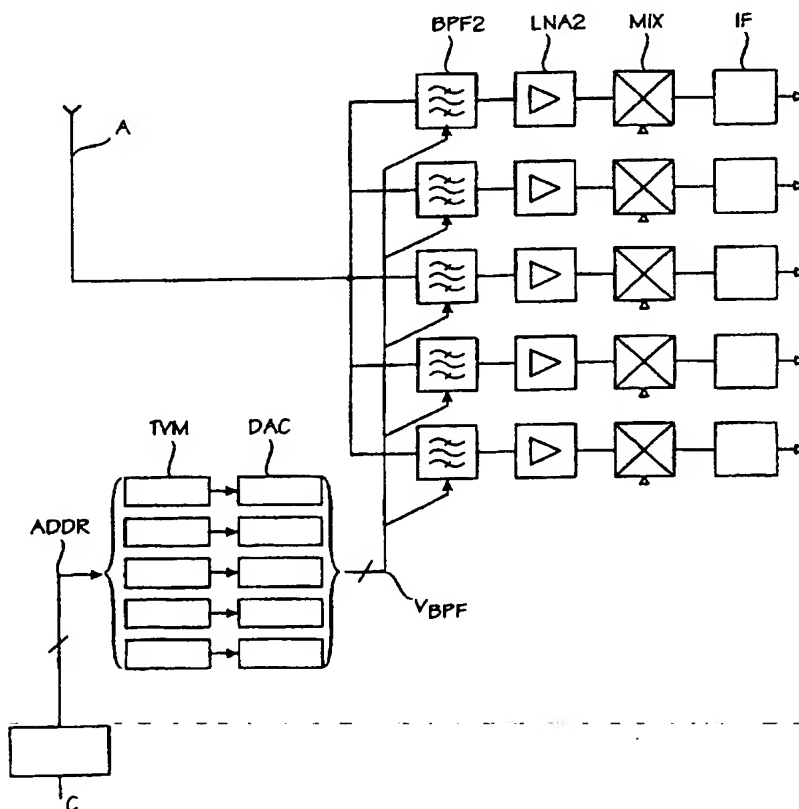
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(71) Applicant (for all designated States except US): NOKIA TELECOMMUNICATIONS OY [FI/FI]; Upseerinkatu 1, FIN-02600 Espoo (FI).			
(72) Inventor; and (75) Inventor/Applicant (for US only): DEKKER, André [NL/FI]; Urpiaisentie 13, FIN-90540 Oulu (FI).			
(74) Agent: OY KOLSTER AB; Iso Roobertinkatu 23, P.O. Box 148, FIN-00121 Helsinki (FI).			

(54) Title: MULTI-BRANCH FREQUENCY-HOPPING RECEIVER

(57) Abstract

A method and an equipment for controlling a multi-branch frequency-hopping receiver equipment used in a radio station, especially in a base station of a cellular radio system onto a desired frequency when a band-pass filter (BPF2) responsive to an external control signal (VBPF) has been arranged for each branch of the receiver equipment, the control signal (VBPF) of the band-pass filter being controlled in sync with frequency hopping. The control signals (VBPF) of the band-pass filter (BPF2) are determined for each frequency (C) and each filter (BPF2) and this information is stored in a tuning voltage memory (TVM) from which it is retrieved in sync with frequency hopping.



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MULTI-BRANCH FREQUENCY-HOPPING RECEIVER

The invention relates to a multi-branch frequency-hopping receiver used in base stations of a cellular radio system, for example.

5 Figure 1 shows as a block diagram a method in which a plurality of receivers have been connected to a common antenna A in a multi-branch radio station. The study of the system is affected by the fact that it concerns a frequency-hopping system, in which case the components of the system cannot be very selective on a fixed frequency. This kind of receiver can also
10 be referred to as being "multichannel". In addition to this meaning, the term "channel" may refer, depending on the context, to the nominal frequency of a radio link or a combination of a frequency and a time slot, for example. In order to avoid confusion, in the present application the term "channel" refers to the nominal frequency of a radio link or a combination of a frequency and a
15 time slot, in which case parallel receivers are referred to as "receiver branches".

A broad band-pass filter BPF1 follows antenna A in the direction of propagation of the received signal. It passes through the whole frequency area of the system. The function of the band-pass filter BPF1 is to attenuate image
20 frequencies and other non-desired components of the spectrum. The next stage is a low noise amplifier LNA which is followed by a distribution amplifier DA. A signal is conducted from the distribution amplifier DA to all the receivers of the station so that a second band-pass filter BPF2, a mixer MIX and an intermediate frequency stage IF are at the front end of each receiver. The
25 number of receiver branches in Figures 1 to 5 is 5 as an example, but there may be more or less of them within reason.

The coupling of the distribution amplifier DA to the receivers is not possible simply by connecting the inputs of the filters BPF2 in parallel as because of frequency hopping, the filters BPF2 cannot be made selective
30 enough. This connection in parallel would cause various adapting problems. Instead, a signal is conducted to the band-pass filters BPF2 via a chain of power dividers PD.

It is previously known that in receivers implemented with frequency hopping, the broadband band-pass filters BPF2 of Figure 1 can be replaced by
35 narrowband filters. In this case the inputs of the filters BPF2 can be connected together under certain conditions and they can be connected directly to a low-

noise amplifier LNA without the distribution amplifier DA and the divider chain PD.

As the divider divides the power into two, its theoretical attenuation is 3 dB, but in practice, attenuation is about 3.5 dB. In the case of five receiver
5 branches the attenuation of three branches is 7dB and of two branches 10.5 dB.

A low-noise amplifier LNA and a distribution amplifier PD generate noise in the image frequencies of the mixer. Therefore it is necessary to have after them band-pass filters BPF2 whose function it is to attenuate the
10 penetration/leakage of the local oscillators of the mixers from one receiver to another. Down-conversion takes place in high signal level mixers MIX which are controlled by frequency-hopping local oscillators which are not shown separately. After the mixers MIX, the desired signals are on a fixed frequency, in which case they can be processed further.

15 For example, many high requirements set for the distribution amplifier DA and inflexibility of switching are problems in the prior art solution described above. The distribution amplifier DA has to generate high output power (about 1 W in the GSM environment). It has to be low-noise and very linear to avoid intermodulation distortion.

20 The second problem in the prior art solution is the inflexibility of the connection caused by the divider chain. The divider chain PD is formed of power dividers which induce the required impedance matchings. If there are N receivers, N-1 receivers are needed altogether and at least some of the signal paths have them in sequence $\log_2 N$ rounded up to the next integral number.
25 For example, 5 to 8 receivers require at most 3 successive dividers but the ninth receiver would then have a chain of four dividers.

The third problem with prior art receivers is provided by band-pass filters BPF2 which have to pass the whole desired frequency band but attenuate the many frequencies outside the band as much as possible.
30 Therefore several resonators are needed there and they have to amplified, generally manually in the manufacturing stage. In addition, band-pass filters are bulky and have a high loss.

The object of the present invention is a multi-branch frequency-hopping receiver with which the above problems are solved. The object will be
35 attained by a method and an equipment that is characterized in that the band-

pass filters BPF2 are controlled by an external control signal in sync with frequency hopping.

The advantage of the present invention is primarily that various problems associated with the distribution amplifier DA can be eliminated.

- 5 Furthermore, the receiver of the invention is more flexible and reliable than the prior art receiver described above.

The invention will be now disclosed in more detail in association with various exemplary embodiments, wherein

Figure 1 shows a prior art multi-branch frequency-hopping receiver;

- 10 Figure 2 shows a simple embodiment of the invention;

Figure 3 shows a second embodiment of the invention where LNA amplifiers are distributed to each amplifier branch;

Figures 4 to 6 show frequency responses created as computer simulations;

- 15 Figures 7 to 8 illustrate the requirements set for band-pass filters;

Figure 9 shows a further advanced embodiment of the invention where the dependence of the centre frequency of the filters on temperature has been measured in advance.

- 20 A block diagram of a multi-branch frequency-hopping receiver of the invention is disclosed in Figure 2. With respect to the prior art solution shown in Figure 1, in the receiver of the invention the distribution amplifier DA and the divider chain PD have been left out, the inputs of the filters BPF2 have been connected in parallel and they are fed directly by the low-noise amplifier LNA. Further, the filters BPF2 have been implemented so that their centre frequency
25 can be adjusted by an external signal, preferably by voltage. The control unit CPU controls the system.

- In a simple embodiment, the control of the filters BPF2 takes place so that their centre frequency as a function of the control signal has been measured in advance. This information is stored in a tuning voltage memory
30 TVM. The addressing of the tuning voltage memory TVM will be explained below. The output of the tuning voltage memory TVM, for example a binary number is connected to the input of a D/A converter DAC (Digital to Analogue Converter). If the converter DAC has no internal holding circuit, one has to be installed in between the tuning voltage memory TVM and the converter DAC.
35 The input of the converter DAC is connected to the control input of the filters BPF2 as a signal V_{BPF} .

It is obvious to those skilled in the art that especially the connection between the tuning voltage memory TVM and the D/A converters DAC in Figure 2 (and in Figures 3 and 9 to be explained below) has been explained rather as cause/effect relationships than as separate equipments. It should especially be understood that a separate memory device need not be reserved for each DAC of the D/A converter but tuning voltage memories TVM may also be elements of the memory in which the other parameter data of the radio station has been stored.

In a simple embodiment, the portion of the input of the tuning voltage memory TVM, that is, the address ADDR essential for the invention includes a digital representation of the nominal frequency of channel C. The contents of the corresponding memory location, that is, the output of the tuning voltage memory TVM contains the digital representation of the control signal V_{BPF} measured and stored in advance, with which representation the filter BPF2 has to be controlled in order that the centre frequency of the filter BPF2 would be equal to the nominal frequency of the channel C in question.

In an advanced embodiment of the invention shown in Figure 3, the filters BPF2 have been connected directly to the antenna A, whereby the low-noise amplifier LNA and the first filter BPF1 have been left out. This requires that the filters BPF2 have a sufficiently low loss. In this case a low-noise amplifier LNA2 has been added between the filter BPF2 and the mixer MIX in each amplifier branch. The advantage of this arrangement is that it is often easier to implement a number of amplifiers of sufficiently good quality where one signal passes than one amplifier where many signals pass at the same time. As is known, the peak power of N uncorrelated, equally strong signals is N^2 times the peak power of a single signal. The combined peak power of N separate amplifiers is then only $1/N$ of the peak power required from a common amplifier where N signals would pass at the same time. Furthermore, the assembly formed by N separate amplifiers is more reliable than a single common amplifier. If one branch of several parallel branches fails, the other branches may continue operation.

Figures 4 to 8 illustrate the requirements set for band-pass filters BPF2. It has been assumed in the figures that simple resonators are used in the filters. A better performance would be achieved with a double resonator but it is difficult to make two resonators follow one another over the entire possible frequency range. Furthermore, a GSM receiver is assumed to be

used in Figures 4 to 8, the spacing between the nominal frequencies of the channels being 400 kHz. This is the minimum useful channel spacing feasible from GSM specifications. Channel spacing according to the GSM recommendations is 200 kHz, but the selectivity of mobile stations and base stations does not allow the use of this closely located channels on the same coverage area. For most operators channel spacing is 800 kHz. If channel spacing was 800 kHz, filters where quality factor Q would be half of the case of 400 kHz would be sufficient.

Figures 4 to 6 show frequency responses created as computer simulations with various quality factors Q. For a specific unloaded Q, an optimal loaded Q exists, minimizing the insertion loss. The loaded Q has a specific upper limit, otherwise the band pass of the filters would be too narrow.

The smallest useful Q of an unloaded resonator is 2000 for 400 kHz channel spacing. The insertion loss corresponding to this value is 7 dB. A lower factor of Q than this would cause too much interaction between adjacent channel resonators. This can be seen in Figure 4. The maximum response of outer filters (those with the smallest and greatest centre frequency) is not exactly on the nominal frequency although the unloaded resonators are exactly on their nominal frequencies. When the attenuation of 7dB thus generated is compared with the attenuation (7 or 10.5 dB) of the divider chain, it should also be noted that the solution of the invention eliminates the insertion loss of the broadband filter BPF2, the insertion loss being typically 1 to 2 dB. Also, in the solution of the invention, the insertion loss is the same to all branches of the receiver and it does not change significantly when branches are added.

Figure 5 shows simulations corresponding to Figure 4 but it uses a filter whose unloaded Q is 10,000. As can be seen in Figure 5, in this case the selectivity is better and the insertion loss is only 3 dB. In Figure 6 the unloaded Q is 100,000 in which case the insertion loss is only about 1 dB, which is mainly caused by the signal leaking into adjacent receivers. Generally the channels are not situated this close to one another, for which reason the insertion loss for Q factor 100,000 is only a fraction of one dB.

Figure 7 created as simulations describes how the modulation of the signal distorts as a function of frequency offset in the case of a simple resonator having a 400 kHz bandwidth. Figure 7 shows amplitude (AMPL) and phase (φ). Figure 8 correspondingly shows the attenuation of a modulated

signal as a function of frequency offset. GMSK (Gaussian Minimum Shift Keying) modulation used in the GSM system takes place in theory at a constant amplitude but a frequency offset from the nominal frequency causes an increase in attenuation and a corresponding amplitude error.

5 It can be seen from Figures 7 and 8 that the filters can deviate 60 kHz from their nominal frequencies without a significant effect. Even an offset of 100 kHz would still be tolerable. It should be noted that the decoder (not shown) connected to the output of the receiver sees the filter as part of multipath attenuation and the equalizer (not shown) eliminates some of this
10 distortion.

 The dependence of a temperature uncompensated voltage-controlled resonator on temperature is typically 30 to 100 ppm/°C, that is, 27 to 90 kHz/°C on the frequency range of 900 Mhz in GSM. Temperature dependence can be diminished by compensation techniques. However, it is
15 obvious that resonators manufactured at present have to be placed in a location where temperature is kept constant.

 One advanced embodiment of the invention is shown in Figure 9. In this solution, the dependence of the frequency of the filters on temperature has been measured in advance (with a thermometer T) and stored in memory
20 principally in the same way as the dependence of the frequencies of the filters on the control voltage explained in connection with Figure 2. In this case more memory is of course needed. As an indicative example of the need for memory, 5 receivers, 50 frequencies, 100 temperatures and 2 bytes are assumed for each value of the control voltage of the filter. The total need of
25 tuning voltage memory will be 50 kilobytes. This memory is preferably a non-volatile, reprogrammable memory. Suitable techniques are e.g. EAROM (Electrically Alterable Read Only Memory), Flash memory, CMOS memory with accumulator or battery backup, etc. Calibration information can also be written into an ordinary RAM memory whose contents are stored e.g. on a
30 hard disk in case of power failures.

 One method for implementing the tuning voltage memory TVM is to a great degree analogous to the memory arrangement of the display control of an industrial standard micro computer. In a computer display, the memory is part of the memory space of the processor and the display memory is
35 arranged to have two gates, that is, it can be read to and written from simultaneously. The processor of the computer updates the contents of the

memory asynchronously by processes carried out by the user, for instance. The display control reads the memory synchronously in step with the production of a video signal. In case of a colour display, three video signals have to be produced, one for each primary colour.

5 In this comparison the processor of the computer corresponds to a control unit of a radio station, the normal RAM memory of the computer corresponds to the RAM memory of the radio station, the display memory of the computer corresponds to the TVM tuning voltage memory of the invention, etc. The essential difference is, of course, that there are only three primary
10 colours on the display of the computer, wherefore there are only three DAC circuits, whereas in the radio station of the invention, there is a flexible number of DAC circuits, the number being equal to the number of the branches of the receiver.

As an alternative to the contents of the tuning voltage memory TVM
15 being determined in advance for each filter BPF2 and temperature, it is conceivable that a suitable technique is applied with this invention for forming a test loop between a transmitter and receiver of a radio station. One suitable test loop has been disclosed in the same Applicant's Finnish Patent 92,260. The use of the simple test loop disclosed in this patent restricts the capacity of
20 the base station during calibration as in this technique separate time slots are reserved for transmission and reception. In order to define to which direction calibration is to be changed, three adjacent time slots have to be allocated to both transmission and reception directions, that is, six time slots altogether.

The reduction of capacity can be avoided by applying the technique
25 disclosed in the same Applicant's Finnish Patent 92,966, on the basis of which test measurements are carried out in the time slots of an idle frame of a TCH/F+ SAACH/TF channel structure according to ESTI/GSM recommendation 05.02 or in the time slots of an idle frame of an SDCCH/8 channel structure.

30 Alternatively, the tuning of a receiver may be carried out during one time slot in the following way. A test signal is sent with the transmitter. At the beginning of the time slot the centre frequency of the filter BPF2 is set by adjusting the control signal below the nominal frequency (or alternatively above it). During the time slot the control signal is adjusted to the direction that
35 the centre frequency of the filter BPF2 approaches the nominal frequency and passes it by. At the same time, signal quality, such as signal strength and/or

bit error rate, are measured continuously and the value of the control signal on which the signal quality attains its peak is stored in memory. For example, signal strength during one time slot would produce a graph of Figure 8.

Such a solution is also conceivable that no separate test signal, but normal traffic is used for tuning the receiver. The receiver could be tuned so that the control signals of the filter BPF2 are changed repeatedly slightly upwards or downwards and a statistical study is made on whether the signal quality improves or deteriorates. The changes have to be so small that the operation of the receiver will not be impeded but so great, however, that it is possible to measure their effect.

The explanation above of the invention and its different embodiments are only intended to illustrate the principle of the invention. Various modifications are evident to those skilled in the art without deviating from the spirit and scope of the claims. It should be especially understood that an almost infinite number of different variations are available for controlling controllable filters. The invention has been explained by way of an example in connection with a base station of the GSM system, but it is evident that it can also be applied to other transmission techniques.

CLAIMS

1. A method for controlling a multi-branch frequency-hopping receiver equipment used in a radio station, especially in a base station of a cellular radio system, onto a desired frequency when a band-pass filter (BPF2) responsive to an external control signal (VBPF) has been arranged for each branch of the receiver equipment, the control signal (VBPF) of the band-pass filter being controlled in sync with frequency hopping, **characterized** in that in the method the control signals (VBPF) of the band-pass filter (BPF2) are determined for each frequency (C) and each filter (BPF2) and this information is stored in a tuning voltage memory (TVM) from which it is retrieved in sync with frequency hopping.

2. A method according to claim 1, **characterized** in that

- the control signals (V_{BPF}) of the band-pass filter (BPF2) are determined by calibrating said control signals (V_{BPF}) for each frequency and for each filter and by storing the digital representations of the control signals (V_{BPF}) in the memory (TVM); and

- the digital representations of the control signals (V_{BPF}) of the band-pass filter (BPF2) are retrieved from the memory (TVM) in sync with frequency hopping and they are converted into control signals of the band-pass filter (BPF2), preferably with D/A converters (DAC).

3. A method according to claim 2, **characterized** in that in the method:

- the expected temperatures are classified into predetermined classes and the digital representations of the control signals (V_{BPF}) of the band-pass filters (BPF2) are determined in advance for each class corresponding to a temperature; and

- the digital representations of the control signals (V_{BPF}) of the band-pass filters (BPF2) are retrieved from the memory (TVM) in sync with frequency hopping on the basis of the class corresponding to the prevailing temperature.

4. A method according to claim 2, **characterized** in that in the method the digital representations of the control signals (V_{BPF}) of the band-pass filters (BPF2) are calibrated and stored in the memory (TVM) at predetermined times.

5. A method according to claim 2, **characterized** in that in the method the digital representations of the control signals (V_{BPF}) of the band-

pass filters (BPF2) are calibrated and stored in the memory (TVM) when conditions change, in which case the conditions comprise at least one of temperature, air pressure or humidity.

6. A method according to claim 4 or 5, **characterized** in that
5 in the method the digital representations of the control signals (V_{BPF}) of the band-pass filters (BPF2) are calibrated and stored in the memory (TVM) in the time slots of an idle frame of a TCH/F+ SAACH/TF channel structure of the GSM system and/or in the time slots of an idle frame of an SDCCH/8 channel structure.

10 7. A method according to any one of claims 2 to 6, **characterized** in that calibrating the control signals (V_{BPF}) comprises the steps of:
- generating a test signal whose frequency corresponds to the nominal frequency of the channel (C) to be calibrated;
- receiving said test signal on the channel (C) to be calibrated and
15 determining the quality of the received test signal;
- changing the contents of the memory (TVM) for the channel (C) to be calibrated until the quality of the received signal attains its optimum value.

8. A method according to claim 7, **characterized** in that the test signal is generated by forming a transmission signal which deviates from
20 the nominal frequency of the channel to be calibrated by a duplex distance and the transmission signal is converted by a duplex filter to a reception frequency.

9. A method according to claim 8, **characterized** in that the calibration of the control signals (V_{BPF}) of the band-pass filters
25 (BPF2) further comprises the steps carried out during the same time slot:
- making the centre frequency of the filter (BPF2) deviate from the nominal frequency of the channel by adjusting the control signal (V_{BPF});
- adjusting the control signal (V_{BPF}) of the filter (BPF2) to the direction that the centre frequency of the filter (BPF2) approaches the nominal
30 frequency of the channel and passes it by;
- measuring the signal quality and storing in the memory the value of the control signal (V_{BPF}) of the filter (BPF2) on which the quality of the received signal attains its peak.

10. A method according to claim 1 or 2, **characterized** in
35 that further in the method at least the temperature of the band-pass filters

(BPF2), preferably the air pressure and/or humidity are also kept essentially constant.

11. A method according to claim 2, **characterized** in that the control signals (V_{BPF}) of the band-pass filter (BPF2) are determined by:

5 - making repeated changes to the control signal (V_{BPF}) and/or to its digital representation stored in the memory (TVM);

 - determining statistically on which value of the control signal (V_{BPF}) and/or which value of its digital representation the quality of the received signal attains its peak;

10 whereby the receiver can be calibrated without a separate test signal.

12. A multi-branch frequency-hopping receiver equipment used in a radio station, especially in a base station of a cellular radio system, in which equipment a band-pass filter (BPF2) has been arranged for each branch,
15 **characterized** in that the centre frequency of the band-pass filters (BPF2) is responsive to an external control signal (V_{BPF}) which is controlled in sync with frequency hopping.

13. A receiver equipment according to claim 12, **characterized** in that a common antenna of receiver branches is connected without
20 amplification to the inputs of the band-pass filters (BPF2) connected in parallel and that a low-noise amplifier (LNA2) has been arranged in each branch after the band-pass filter (BPF2).

14. A receiver equipment according to claim 12 or 13, **characterized** in that the control signal (V_{BPF}) to which the medium frequencies of
25 the band-pass filters (BPF2) are responsive is voltage.

15. A receiver equipment according to claim 12, **characterized** in that it further comprises a control unit (CPU) and a memory (TVM) connected thereto in which the medium frequencies of the band-pass filters (BPF2) measured in advance in response to the control signal (V_{BPF}) are
30 stored, whereby an address (ADDR) of the memory (TVM) is responsive to the desired centre frequency of the filter (BPF2) in a predetermined way.

16. A receiver equipment according to claim 15, **characterized** in that the memory (TVM) is a non-volatile memory.

17. A receiver equipment according to claim 15, **characterized** in that the memory (TVM) is a reprogrammable memory.
35

18. A receiver equipment according to claim 15, **characterized** in that the radio station further comprises a temperature measuring means (T), the temperature information (VT) derived from which is operatively coupled to the same control unit that controls the memory (TVM); and that the
5 centre frequencies of the band-pass filters (BPF2) in response to the temperature measured in advance are also stored in the memory; and that the address (ADDR) of the memory (TVM) is responsive to the measured temperature in a predetermined way.

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Fig. 2

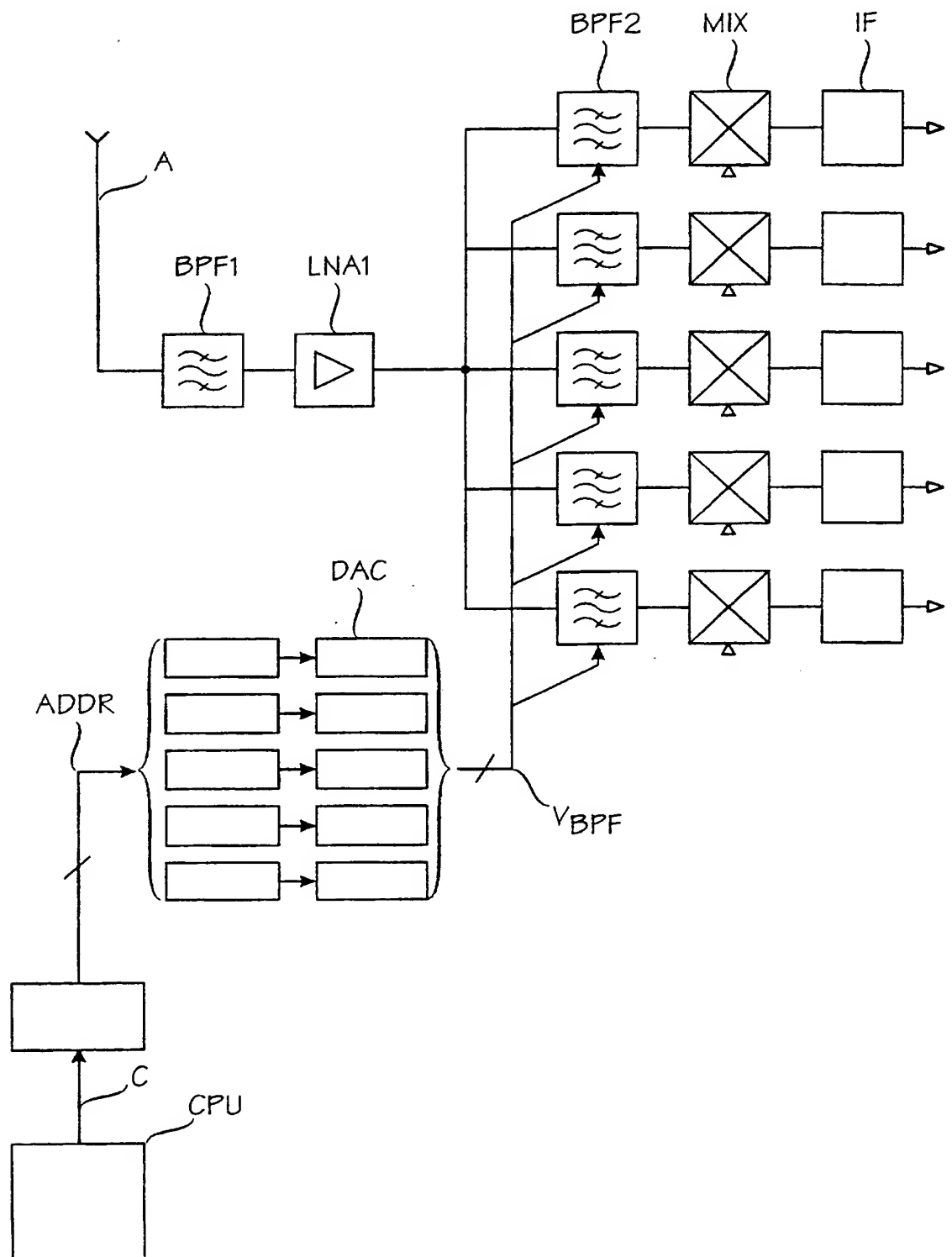
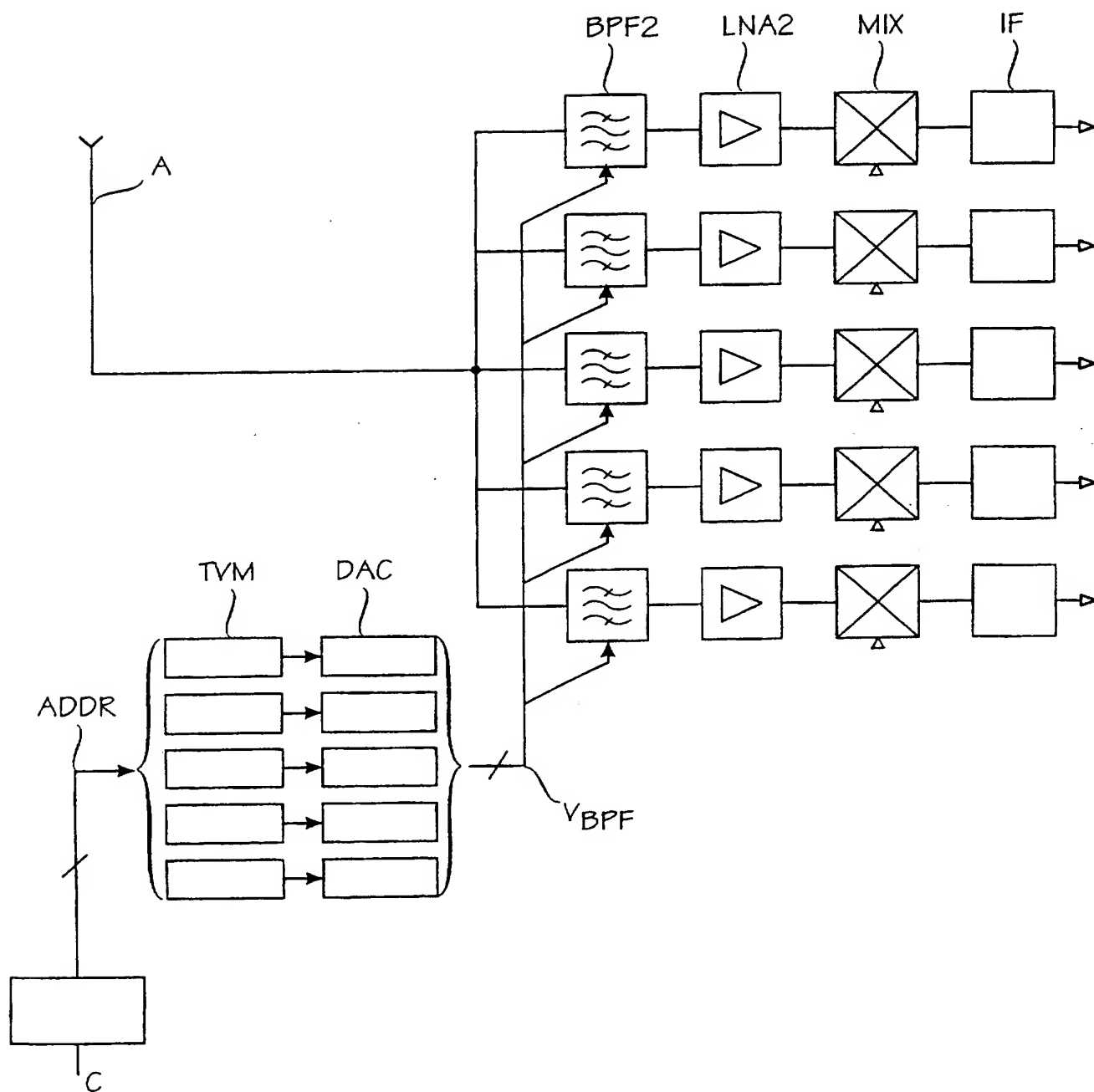
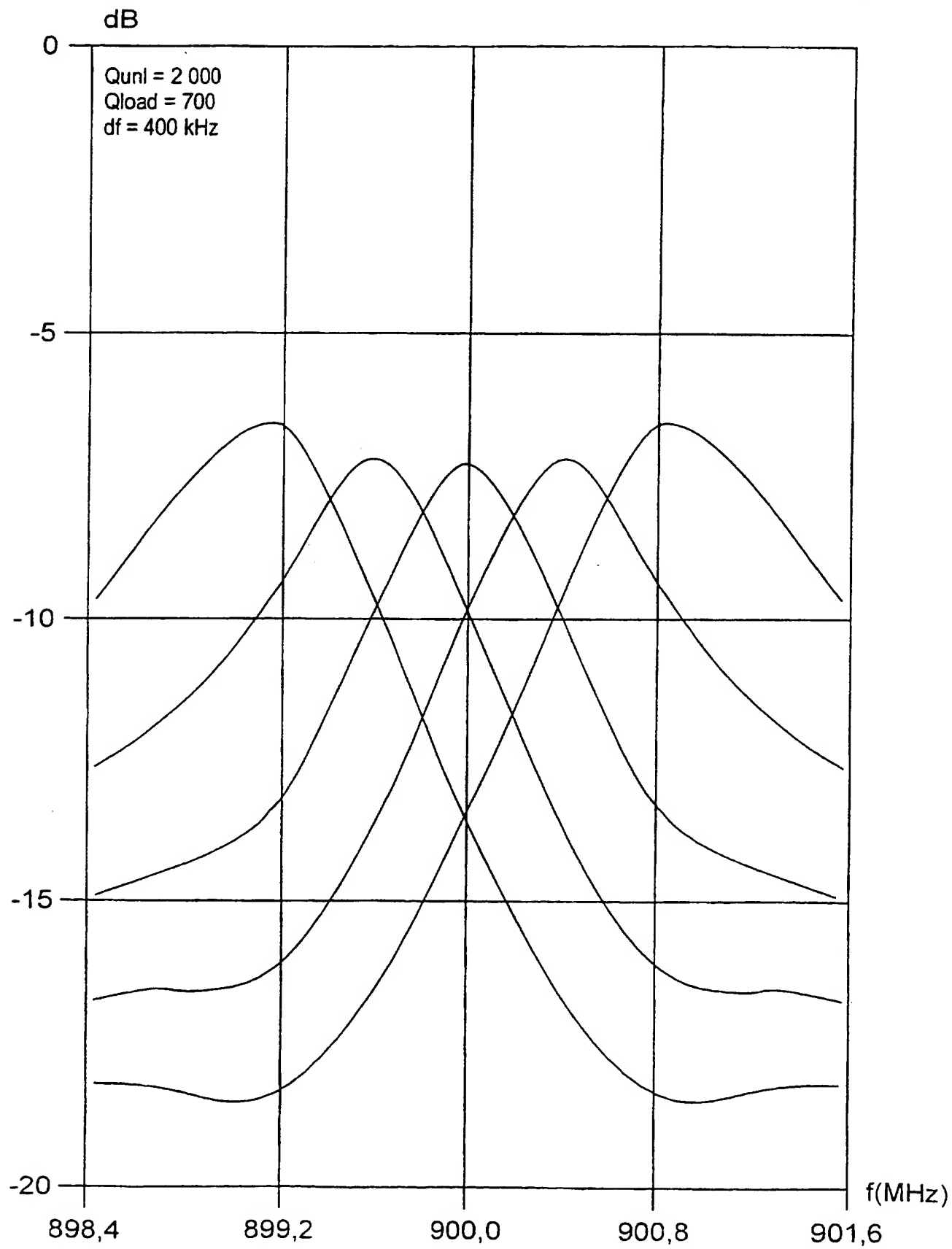


Fig. 3



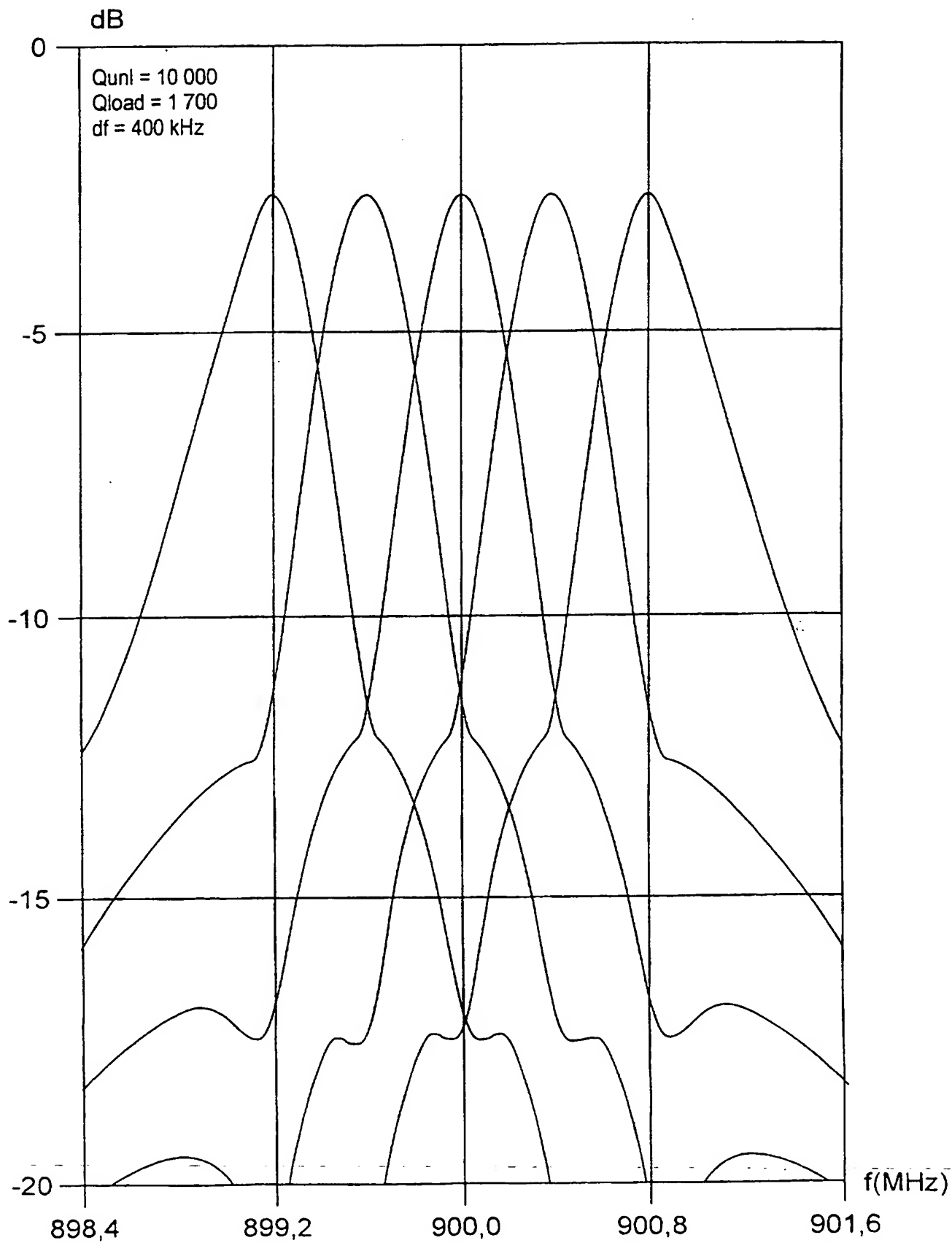
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Fig. 4



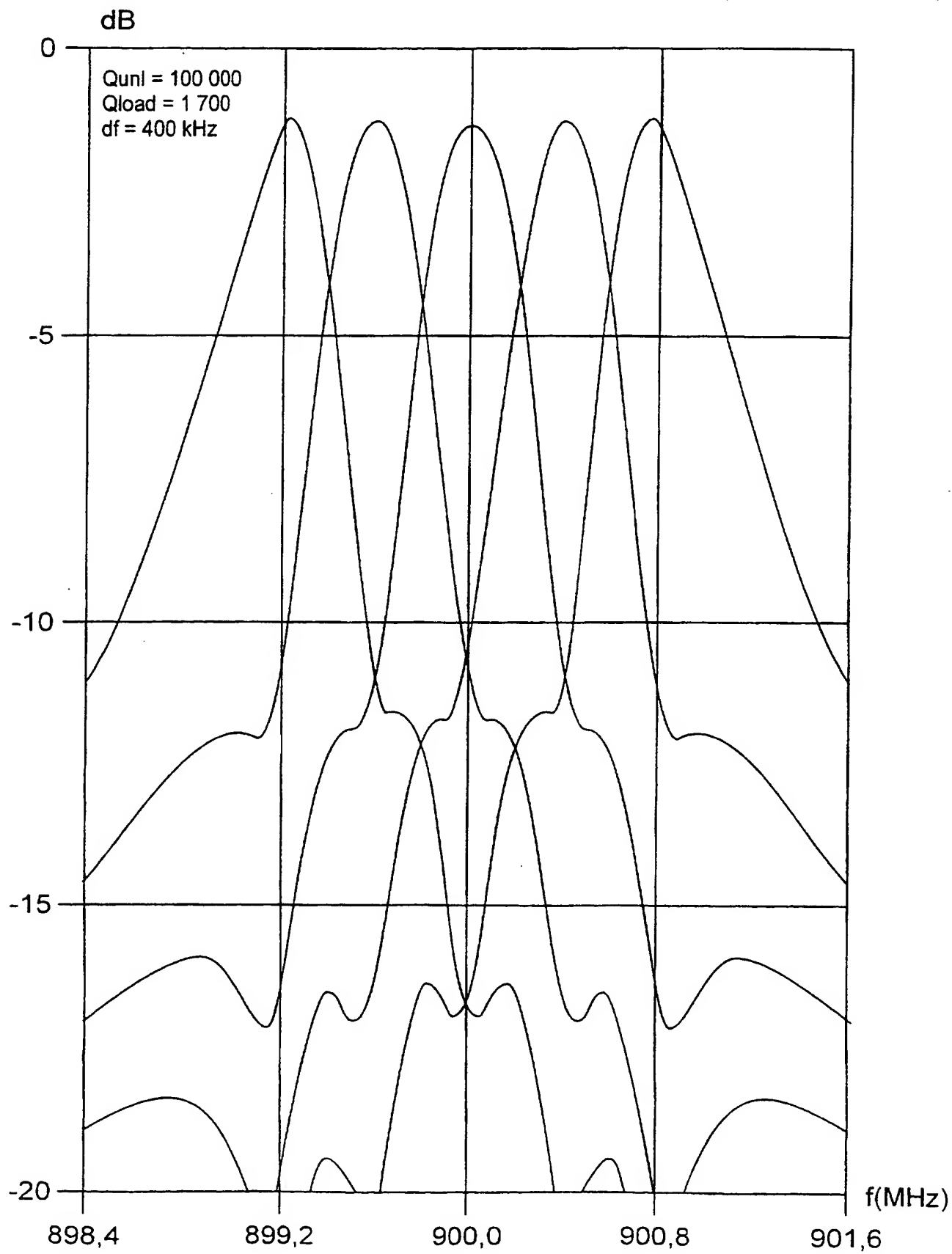
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Fig. 5



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Fig. 6



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Fig. 7

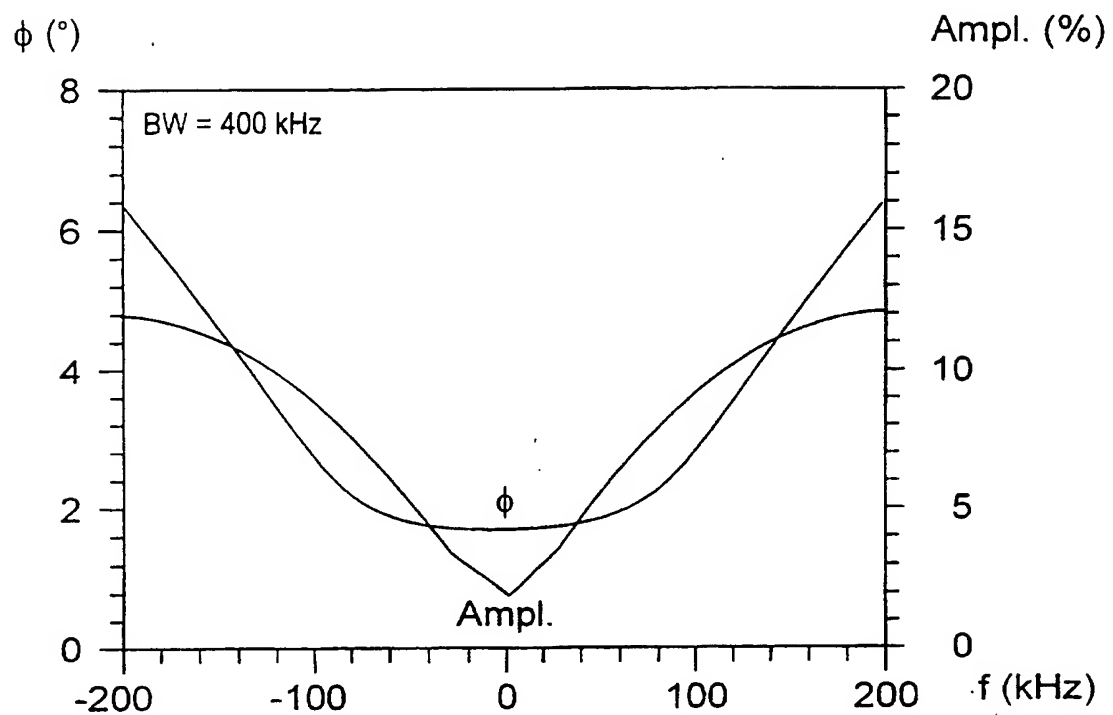
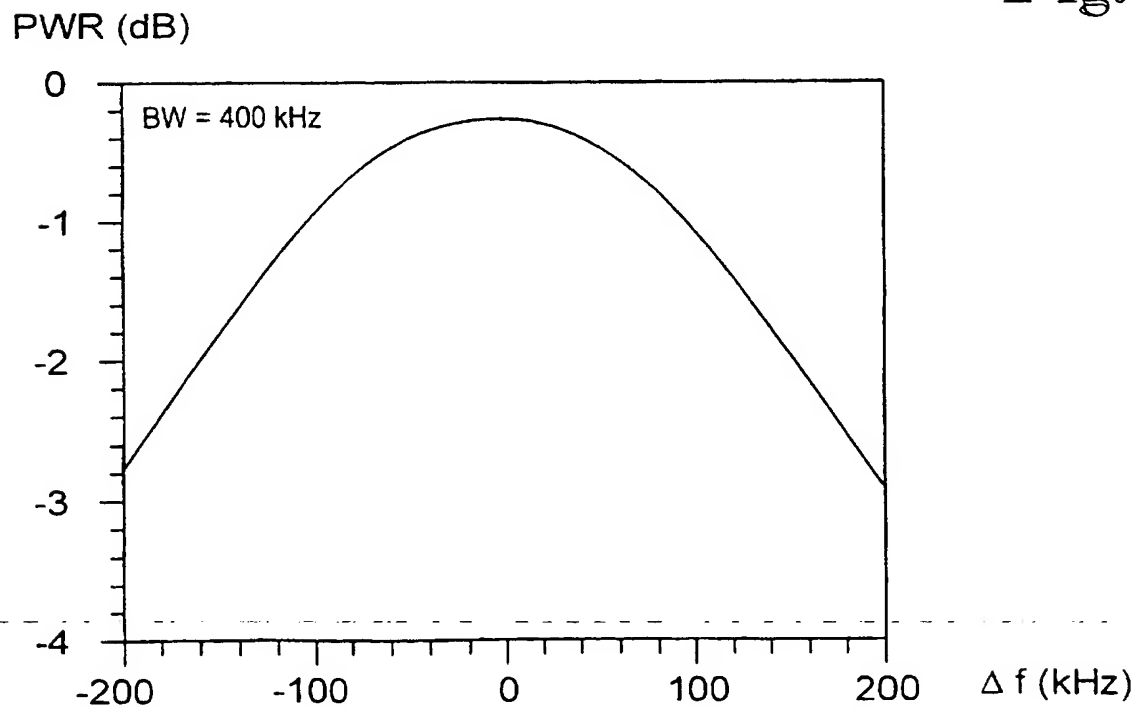
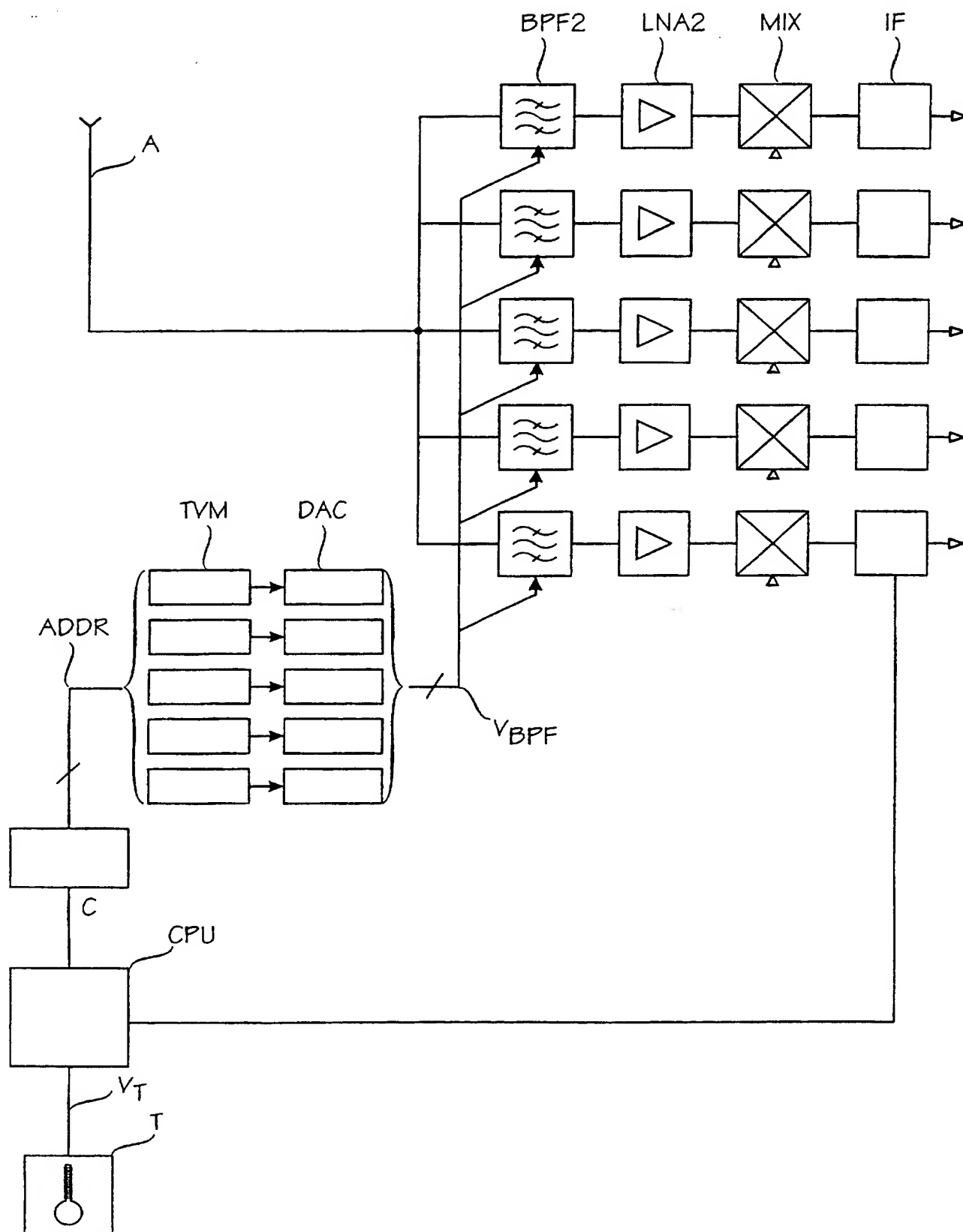


Fig. 8



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Fig. 9





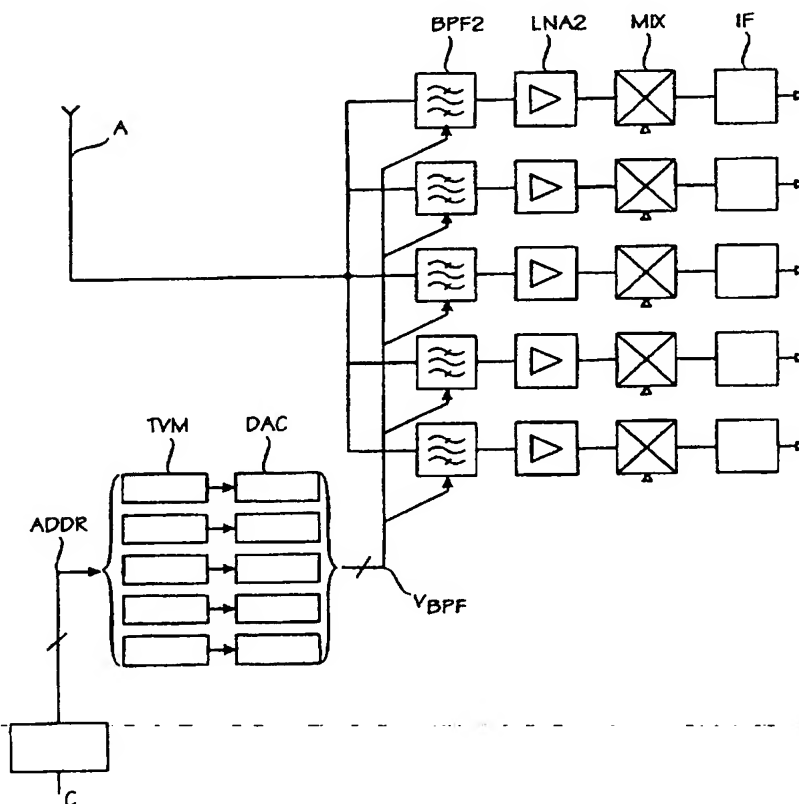
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(71) Applicant (for all designated States except US): NOKIA TELECOMMUNICATIONS OY [FI/FI]; Upseerinkatu 1, FIN-02600 Espoo (FI).		(88) Date of publication of the international search report: 21 August 1997 (21.08.97)	
(72) Inventor; and (75) Inventor/Applicant (for US only): DEKKER, André [NL/FI]; Urpiaisentie 13, FIN-90540 Oulu (FI).			
(74) Agent: OY KOLSTER AB; Iso Roobertinkatu 23, P.O. Box 148, FIN-00121 Helsinki (FI).			

(54) Title: MULTI-BRANCH FREQUENCY-HOPPING RECEIVER

(57) Abstract

A method and an equipment for controlling a multi-branch frequency-hopping receiver equipment used in a radio station, especially in a base station of a cellular radio system onto a desired frequency when a band-pass filter (BPF2) responsive to an external control signal (VBPF) has been arranged for each branch of the receiver equipment, the control signal (VBPF) of the band-pass filter being controlled in sync with frequency hopping. The control signals (VBPF) of the band-pass filter (BPF2) are determined for each frequency (C) and each filter (BPF2) and this information is stored in a tuning voltage memory (TVM) from which it is retrieved in sync with frequency hopping.



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INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI 96/00684

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04B 1/713

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0166551 A1 (AIRTECH LIMITED), 2 January 1986 (02.01.86), figure 1, claims 1,2, abstract -----	1-18

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Date of the actual completion of the international search

27 June 1997

Date of mailing of the international search report

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Name and mailing address of the ISA/
Swedish Patent Office
Box 5055, S-102 42 STOCKHOLM
Facsimile No. +46 8 666 02 86

Authorized officer

Mikael Sollerhed
Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

03/06/97

International application No.
PCT/FI 96/00684

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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02/01/86

DE 3566338 A

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